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ON THE CLIFFS AND EXOTIC BLOCKS OF NORTH  
SWITZERLAND.

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THE cliffs and exotic blocks that occur along the north border of the Alps and Carpathians have long remained as exceptional in occurrence and as difficult of explanation as were for years the so-called newer gneisses lying upon the early palæozoic sediments of northwest Scotland. The following paper is a brief summary of the work of two summers along the cliff-belt in Switzerland, chiefly in the region of the Lake of Lucerne where these phenomena are most typically developed. It will be my endeavor to present and discuss some of the problems which this work has suggested rather than to give a description of the region.

*Introduction and definition of terms.*—A glance at a good geological map of Switzerland<sup>1</sup> shows that the northernmost chains of the Alps, striking about E. N. E.—W. S. W. between Interlaken and the Upper Rhine valley (near the Sentis) are composed of Cretaceous strata with only rarely a patch of Jurassic rock exposed in the more deeply eroded anticlines and with Tertiary deposits filling in the synclines and in places reaching up over the backs of the more depressed Cretaceous folds.

These Tertiary beds require our first attention. They consist of a thick series of gray or bluish slaty clays, shales and marls with subordinately included banks of limestone, sandstone, brec-

<sup>1</sup> V. Geologische Uebersichts Karte der Alpen, by DR. FRANZ NÖE 1 : 1,000,000, Vienna, 1890, \$2.50.

"cliffs." A careful comparison of the cliff masses however with the exotic blocks showed that the two are the same. In point of size as well as facial development no distinction could be established between them, for the same strata containing the same fauna occur in both and in point of bulk the exotic block masses were found to occur in all sizes up to those of the smaller cliff masses. In the accompanying map the distinction between the two is a purely arbitrary one, the attempt being made simply to indicate the masses previously recognized as "cliffs" in the literature of the subject for convenience in discussion.

*Historical.*—Before proceeding to the results of my own studies I may introduce a brief sketch of previous work. On account of the scarcity of fossil remains in them the Swiss cliffs were long thought to be in some unexplained way mere abnormal developments of the strata of the adjacent chains and to be therefore of Cretaceous age. The petrographic similarity of one of the cliff strata now known to be Jurassic, to the Swiss Cretaceous Seewenkalk gave color to this idea. In 1875 Professor F. J. Kaufmann succeeded after long and patient search in discovering a set of fossils which proved beyond all doubt that the cliff masses on the Lake of Lucerne (Mythen, Buochserhorn, Stanzerhorn, and also the group to the southwest by Giswyl) contained a strata of Jurassic age.<sup>1</sup> Subsequent studies especially those of Stutz<sup>2</sup> have confirmed this and added to our knowledge of the fauna. The group of cliff-like masses to the east of the Mythen Iberg (see map) were at this time not recognized as belonging to the cliffs, as Kaufmann had in 1871 after a brief reconnoissance declared them on stratigraphical grounds to be a transition deposit between the uppermost Cretaceous and the base of the Jurassic. In 1889 Professor Steinmann upon further examination compared the strata here found in part with the Trias and Jura of Algau in the East Alps and held them to be of corresponding age. My own studies in 1891 and 1892 con-

<sup>1</sup> F. J. KAUFMANN, Fünf neue Jurassier, Jahrbuch des Schweits. Alpen Clubs, XI. Jahrgang, separate.

<sup>2</sup> STUTZ: Das Keuperbecken am Vierwaldstättersee, Neues Jahrbuch, 1890, II., p. 99.



4. *Raible Marls*, dark gray to black, sometimes sandy, with *Equisetum columnare*. Unknown in Switzerland outside of exotic series.

5. *Rötidolomite*, yellow to rust colored, compact, crystalline. Found in Helvetian series.

6. *Haupt Dolomite*, hard, gray, sugar-grained dolomite, with angular fracture, very characteristic in the landscape. Found in Switzerland only in the exotic series.

7. *Rhätic*, gray to black crystalline limestone with *Avicula contorta*, very characteristic. Not found in Switzerland outside of the exotic series.

#### *Jurassic.*

1. *Liasic Fleckenkalk*, gray, brittle limestone w. black spots as if colored by bitumen. In Switzerland restricted to exotic series.

2. *Crinoidal Limestone of Lias*, brown to red, colored by iron; *Terebratula erbaensis*, Suess; *Rynchonella mutans*, Rothpl. In Switzerland only in exotic series.

3. *Crinoidal Limestone of Dogger*, like last, with *Pecten verticillatus* Stol., *Ammonites Sowerbyi*, etc. In Switzerland known only in exotic series.

4. *Birmensdorf beds*.—"Calcaire concrétionné" (?), hard, gray limestone in small rounded or lens-shaped masses imbedded in gray clay shale with (?) *Phylloceras*. Found only in exotic series in Switzerland.

5. *Malm*.—"Châtel limestone" of Studor with *Aspidoceras acanthicum* Opp., *Aptychus punctatus* Park, etc. Found only in exotic series.

6. *Radiolarian Chert*.—Red with iron, filled Radiolaria and associated with red clay. In Switzerland only in exotic series.

7. *Aptychus Limestone*, red and white fibrous limestone poor in macro-fossils (*Aptychus* and *Inoceramus*) but rich in *Foraminifera*. In Switzerland found only in exotic series.

#### *Cretaceous.*

*Berrias beds*, gray shales with *Aptychus angulicostatus*. Found also in northern chains of Swiss strata.

It will be seen that of the fifteen formations found in the exotic

series three only—the Rauhwacke with the associated gypsum; the Röt dolomite and the Berrias beds, *i. e.*, two near the bottom and one at the top of the strata—are also found in the normal Helvetian series. In the strata between these we find in Switzerland in the Trias, which is in general but weakly developed, nothing at all to correspond to the characteristic Muschelkalk, Haupt dolomite, Contorta beds (Rhätic) etc. In the Jurassic of Switzerland we find a series of clay shales, sandstones, iron oolites and gray crinoidal limestones with fossils of middle European type and differing throughout from those found in the cliffs. These are followed by thick series of dark colored limestone with Jura facies in general.

*Geologic relations of cliffs to their surroundings.*—The differences which we thus see in the facial development of the Swiss strata and of the cliff or “exotic” strata of *the same age* lying side by side with them in north Switzerland, and beside which the correspondences seem quite insignificant, are so striking as to stimulate inquiry as to their cause and possible explanation.

The attempt was therefore first made to determine the relations which the cliff masses sustained to the surrounding Helvetian chains, to determine if possible whether these masses extended *down through* the Flysch above which they rose or simply lay as rootless block masses *upon* the Helvetian chains. It will naturally be impossible for us to enter here with any detail into a line of evidence based to a great extent upon local structural relations of the region studied and involving a considerable mass of local description and local facts.<sup>1</sup> There are, however, certain general features common to and characteristic of the cliffs to which I may refer. One line of such evidence is furnished by the conditions of the strata in the cliffs as contrasted with those near them. A second by the more general relations of the cliffs to the surrounding chains.

If the cliff masses be superficial in their nature, they must have been thrust from the side, and we should in that case find evidence of such overthrust in the cliff masses them-

<sup>1</sup> For these details cf. Beiträge z. geol. Karte d. Schweiz, Vol. XXXIII, Bern, 1893.

cias and conglomerates of early Tertiary (Eocene) and everywhere known under the name of *Flysch*. The thickness of the whole is, because of complicated movements which have taken place and the monotony of its petrographical characters, very difficult to determine. It has at some points been pinched out to a few feet; at others it is apparently several hundred feet in thickness.

This formation known as the *Flysch* is of especial interest to us because it is in it that the "cliffs" occur. The geological term "Klippe" or cliff, if we translate the term, was originally applied on account of the striking and abrupt manner in which these masses rise above their level or gently rolling Tertiary (*Flysch*) surroundings like cliffs above a beach. As geologists have learned more of the true nature of these masses, the term has come to take on a more definite geological significance, and is now somewhat loosely applied to island-like masses of rock which are stratigraphically, palæontologically, petrographically, and usually orographically foreign to the region in which they occur. Thus the Mythen overlooking the Lake Lucerne a short distance east of Brunnen and the Rigi are good types of the class—isolated masses, striking in appearance and composed of strata which have been found *in situ* nowhere else in all Switzerland.

To the rocks found in the cliffs the term "exotic" has been applied to express their foreign nature and to distinguish them from the "erratic" material brought down by the glaciers.

The exotic material of the cliffs consists of masses of dolomites, marls, shales and sandstones in certain of which characteristic Triassic and Jurassic fossils have been found. It lies upon or more or less imbedded in the soft Tertiary *Flysch* shales and the masses of it range in size from the smallest angular fragment up to cliffs a half mile and more in length and several hundred feet in height.<sup>1</sup> Of these the smaller blocks which were obviously loose, disconnected masses have been long known as "the exotic blocks" of the *Flysch*, while the more pretentious masses which on account of their size were *apparently in situ*, were termed

<sup>1</sup> For comparison v. Neumayr's description of the Carpathian cliffs which are often much larger than this. *Erdgeschichte*, Leipzig, 1887, Vol. II., p. 672.

selves. Such we do find. All of the cliff strata show evidence of great pressure; they are fractured and often traversed thickly with calcite veins (especially the harder Haupt-Dolomite and the Tithon); the less brittle rocks are strongly contorted and full of cleavage structure and of slickensides (especially the softer Tithon beds of the cliffs); certain of the less resistant beds (as the Aptychus limestone and Raible marls on the Roggenstock and Laucheren) are greatly thinned by pressure or in places entirely pinched out. All these features are evidence of strong pressure, but more striking is the further fact in this connection, viz., that all evidence of disturbance, such as is found in the cliff masses and I may also add in the larger exotic block masses near the cliffs, is entirely wanting in the Helvetic strata all about. It might of course be said that the evidences of pressure mentioned would be as well accounted for if the cliffs were thrust powerfully upward from below through the younger Swiss strata upon which they lie, as has been thought by Professor Neumayr to be the case with the Carpathian cliffs. But at Iberg and in the other larger cliffs in the region of the Lake of Lucerne it is hard to see how such an upward thrust could have taken place powerful enough to force masses half a mile long through beds of limestone (Urgonkalk, Gault and Cenoman) several hundred feet thick without showing some evidence of the disturbance in the rock thus thrust through at least in the immediate vicinity of the cliffs. Such evidence, however, we fail to find either in the alteration of the general strike or dip of the Swiss beds or in indications of pressure in the minute structure of the rock itself. This contrast indicates that the one set of rocks has undergone disturbance which the other has not, and that the two have been affected by a different set of dislocations. In the Roggenstock near Iberg the cliff strata lie nearly horizontal. The Swiss strata below them are also nearly horizontal at this place. This position is what we would expect were the cliff thrust from the side, but very difficult to understand if they were thrust from below. The long, low mass of the Laucheren-Mördergrube cliff presents also the same difficulty on the latter hypothesis. Again the strata



on the Roggenstock and the Kleine Mythe are not only nearly horizontal but actually in *inverted order* with younger strata below and older above. This complete inversion seems impossible to explain on the theory of an upthrust yet it is a common phenomenon accompanying powerful lateral thrust.

Without entering here into further details I may mention one or two facts of more general significance bearing on the relations of the cliffs to the surrounding strata. One very singular feature is the fact that the Swiss cliffs and the exotic blocks as far as I know them, invariably occur in the Tertiary Flysch shales. In spite of the extensive erosion which has attacked the whole region in which the cliff phenomena occur *the cliffs are found nowhere where the Flysch has disappeared*. If they came up from beneath, through the Cretaceous and Tertiary, we should surely expect to find hard and resistant limestones and dolomites of the cliffs at some points remaining after the softer Flysch shales had been eroded away, or at least some point where the cliff had not been thrust entirely through the Flysch and exposed between the jaws of a Cretaceous anticline on its way through. We find it difficult to see on the upward thrust hypothesis why the whole exotic phenomena should be dependent upon the presence of the Flysch. At Iberg we have a striking example of this dependence. It will be seen on a good general map that owing to a local sinking of the Swiss chains at this place, Flysch shales extend farther southward than they do to the east or west of here, continuing up over the top of the Roggenstock-Fallenfluh anticline, though usually confined to the troughs, and here also peculiarly enough the cliffs occur, *i. e.*, on the top of this anticline though more commonly the exotic phenomena appear in the Flysch-filled synclines only. If the Iberg cliffs could have come from beneath and be therefore associated in origin with the Swiss chains, it is difficult to understand why in the the strike of the anticline to the east and west of their present position they should disappear as soon as the Flysch disappears. This relationship between the cliffs and the Flysch becomes intelligible, however, as soon as we conceive of the exotic masses as thrust from the side and *thrust over Flysch* upon which and in

which they lie, so that the erosion of the latter would necessarily bring about the erosion and disappearance of the former. Another striking feature of the cliff masses is to be found in the fact that in spite of the confusion into which they have been thrust they give evidence of a generic if not of an earlier actual physical connection with one another from the fact that they show in certain cases a notable *correspondence of irregularities* in two adjacent cliffs. Thus the Roggenstock and the adjacent Laucheren cliffs both present to us Triassic "Haupt Dolomite" lying upon Jurassic Aptychus limestone, and the striking correspondence of strata in the two neighboring masses of the Stanzerhorn and the Buochserhorn has been already remarked by Stutz in his description of them. This would be what we should expect were the cliff masses part of a general overthrust, much confused as a whole, but still showing in places evidence of the original unity of the entire mass.

The last two points suggest a third. If the cliffs are part of a general overthrust, as the whole region has been strongly eroded we might expect to find traces of the original overthrust in the material brought down by the agencies of erosion and deposited along the foot of the Alps. Singularly enough we do find in the Miocene lowlands stretching along the north border of the Alps a vast amount of material in fragments from a fraction of an inch to five or six feet in diameter and much water-worn as a rule, but often fossiliferous, and showing in striking degree the same facial development as the cliff series. This material occurs in thick banks of a more or less consolidated conglomerate known under the name of *Nagelfluh*. Dr. Früh, of the University in Zurich, who has given us the most complete account of this conglomerate, described from it "Muschelkalk," Diplopora Limestone, Rauhwacke, Haupt Dolomite, Rhaetic, "Fleckenkalk," Hierletz beds, Aspidoceras beds, Radiolarian chert and Aptychus limetone. A comparison with the table of cliff strata given above will show the striking similarity between the two. The evidence of very extensive erosion of cliff material thus afforded by the study of the Nagelfluh furnishes additional proof that the cliffs are but the last remnants of a once

much more extensive cap covering the outer Alpine chains. Were the cliff masses thrust upward from below through the Helvetian Cretaceous and Tertiary anticlines we could hardly expect to find so much eroded material derived from them as we do indeed find in the Nagelfluh. For in that case we should expect the cliff masses to be in some places less completely thrust through the encasing younger strata, and therefore more or less completely hidden by them, so that the cliffs would become exposed to its action only after erosion had removed the younger covering. We should therefore expect to find the cliff masses increasing in number and extent as deepening erosion exposed them more and more to view. We find, however, abundant evidence that the cliffs cover a much less extensive area today than formerly. Again in case of an upthrust from below we should further expect that the percentage of cliff strata in the material carried from the surface by erosion would have been less in former times than it is today—it could surely not have been greater. An examination of the stream beds coming from the cliff belt shows today a decided preponderance of Helvetian over cliff strata in general. Instead now of finding in the Nagelfluh, as we would expect an even greater preponderance of Helvetian over cliff strata we find the amount of Helvetian rocks insignificantly small. This striking fact can, as it seems to me, only be explained on the ground that the Helvetian strata were at the time of the deposit of the Nagelfluh to a considerable degree protected from the erosion which attacked and carried down to the Miocene seashore vast quantities of cliff material. To assume that the protection consisted in a cap of cliff strata which covered large portions of the outer chains would be in harmony with the theory of overthrust but seems to be quite inexplicable on the hypothesis that the cliff masses were pushed up through the strata where they occur.

With this imperfect summary we have endeavored to give some of the more important reasons for believing that the Swiss cliffs are superficial phenomena lying upon the surface of the normal Swiss series and immediately upon the Flysch and have been therefore thrust from the side into their present position.

*Origin of the cliffs.*—We now approach another, perhaps the most difficult question relating to the cliffs—the question of their origin. As the cliff masses themselves do not furnish us direct evidence of the direction from which they may have been thrust, we are led to look for other and indirect evidence. The solution of this problem must depend therefore in great part upon the study of the faunal characters and relationships of the exotic strata, in connection with the stratigraphy, their petrographic characters and their distribution. An important circumstance and one which has probably retarded more than anything else the acceptance of the idea of overthrust, is the fact that, in distinction from the analogous phenomena in France, Scotland and America, in Switzerland no rock masses are known which contain *in situ* the strata and fossils found in the cliffs and whence therefore the cliff masses could be supposed to have proceeded. It has seemed therefore quite impossible to trace them to their original home or basin of deposit. In looking for the basin of deposit of the cliff series the region to the south of the cliff zone is soon seen to be excluded for reasons already indicated, viz., that the faunal and other characters of the exotic series are so entirely distinct from those of the Helvetian series which occupy all the district of the Glarnese Alps to the south, and although to the south still further strata bearing the same facial characters are known in the vicinity of the Italian Lakes the extreme distance of these outcrops, sixty-five miles or more, as well as the physical character of the intervening Alps, effectually precludes the possibility of deriving the cliffs from that quarter. As the cliff masses were evidently not introduced from the east or west we are led to look to the plains to the north (schweizer'sche Hochebene). Many years ago the famous Swiss geologist Studer for reasons quite different from those here considered was led to believe in the existence of a sunken mountain system<sup>1</sup> buried beneath the young (Miocene) strata of the Swiss plains which has since been assumed to exist by numerous other geologists and has received the name of “das Vindelisische Gebirge” from Professor Gumbel.

<sup>1</sup> Cf. Profiles in STUDER'S *Geologie der Alpen*, Vol. II., p. 434–436.

The study of the cliffs has brought us back to this old hypothesis with renewed assurance of its innate probability.

In considering this question it is important to have clearly in mind the relations sustained by the "East Alps" (that portion of the Alps lying to the east of the Rhine) on the one hand, and by the Freiburg Alps to the west of Lake Thun on the other to our cliff masses. (Compare accompanying map.) The East Alps bound the cliff zone on the east as do the Alps of Freiburg on the west. Both the East Alps and the Alps of Freiburg have long been known to contain a Mesozoic rock series facially quite distinct from those of the normal Swiss mesozoic, so that the term "Helvetian (Swiss) series," "East Alpine series" and "Freiburg series" have been used to distinguish the three. Since the time of Brunner's discovery of *Avicula contorta*, a characteristic East Alpine upper Trias form, in the Alps of Freiburg (Stockholm) it has been repeatedly pointed out that there are numerous features of resemblance between the strata of these two territories lying at either extremity of our cliff zone. Realizing the importance of establishing this point and the relations of the cliffs to the whole, I undertook to make a tabulation of the strata and fossils of the Trias, Jura and lower Cretaceous (all occurring in the cliffs and exotic blocks) of (1) the "East Alps," (2) the cliffs and exotic blocks, and (3) the Alps of Freiburg. The result of this comparison has shown that the strata of all three have essentially the same facial development, and might belong therefore to the same basin of deposit. (For the geographic relations of these regions see map.) The importance of this point for the understanding of the cliffs can hardly be overestimated. It shows us that the basin of deposit of the East Alpine series was not confined to the east of the Rhine, but extended, or at least repeated itself, far to the west of it along the north border of the Alps; it shows us further that the cliff zone stretches between the East Alps and Freiburg Alps as the remnant of a once more or less continuous deposit connecting the two; and it leads us to suspect that on the same basis of unity whatever greater movements have taken place in the cliff

masses would be very likely to have similarly affected the strata of the Alps of Freiburg. In order to test this point I visited the Alps of Freiburg in the summer of 1893. We ought here to be able it was thought (1) to distinguish clearly between the "Freiburg" (exotic) and the normal "Helvetian" series and therefore determine by direct examination at the place of contact between the two kinds of rocks whether the Freiburg strata show evidence of an overthrust southward upon the Swiss chains as we had been led to assume was the case with the cliffs. The results of these investigations, published elsewhere,<sup>1</sup> showed evidence of an overlapping of Freiburg strata southward 4.5 kilometers upon normal and characteristic Helvetian beds, which were disclosed in the deeply cut valleys of the upper Simme and Saane rivers. Here, too, we find the same sharp contrast between the excessively disturbed and often inverted Freiburg strata and the horizontal Helvetian series that we noted in the cliff zone to the east; also similar breccias occur on the plane of overthrust. Here, too, as in the vicinity of Iberg, the overthrust is everywhere over the Flysch, so that the time of the movement corresponds to the time of movement farther east.

Another feature which favors the view of overthrust from the north is to be found in the peculiar distribution of the exotic material over the belt occupied by the cliffs. Here I cannot perhaps do better than to refer to the accompanying sketch map where this feature is indicated, and point out what the map is intended to show.

#### EXPLANATION OF THE SKETCH MAP.

The map of North Switzerland shows the distribution of the cliff masses and "exotic blocks" of North Switzerland in the cliff zone extending from Lake Thun to the Rhine and the relation of this cliff zone to the surrounding country. All portions colored black, either solid or diagonally striped, represent exotic material. The size of these masses has been necessarily exaggerated in the map, though the relative size of the different

<sup>1</sup> *Berichte der naturforschenden Gesellschaft zu Freiburg in Baden*, Vol. IV., No. 2.

exotic masses among themselves and their relative abundance has been expressed as well as possible.

In this cliff zone the rounded black patches represent the larger cliff masses as follows :

- No. 1 (eastermost cliff known) = Berglittenstein cliff, in the Toggenberg syncline near Grabs.
- No. 2 = Roggenstock cliff, near Iberg in Upper Sihl valley.
- No. 3 = Laucheren-Mördergrube cliff, near Iberg.
- No. 4 = Schien-Gründelhüttle cliff, two masses near Iberg.
- No. 5 = Zweckenalp cliff, near Schwyz, Lake of Lucerne.
- No. 6 = Die Mythen cliffs—three masses near Schwyz.
- No. 7 = Buochserhorn cliffs—three distinct masses according to Heim<sup>1</sup>; five according to Stutz<sup>2</sup>; on Lake of Lucerne.
- No. 8 = Stanzerhorn cliff—near Lake of Lucerne.
- No. 9 = Giswyl cliffs—several more or less disconnected masses.
- No. 10 = Niederhorn cliffs—three small exotic masses described by Kaufmann,<sup>3</sup> near the northwest foot of the Niederhorn.  
(I may also mention here for completeness, farther to the west.)
- No. 11 = Lenk-Lauenen cliffs<sup>4</sup>—exotic masses in the Upper Saane valley between Lenk and Lauenen.
- Nos. 12 and 13—Westernmost cliff-like masses = Thônes masses—thought to be “cliffs,” to the southwest of the Chablais region.<sup>5</sup>

In this same Thun-Rhine cliff zone are also represented, as well as could be in a map of this size, the distribution of the smaller exotic masses or “exotic blocks” (in general those masses that are less than 25 meters in diameter) as far as I have been able to determine their presence either by personal visit or, as in one instance (H), from the literature alone. There is undoubtedly much more such material in the Flysch which further search will reveal. The principal groups of exotic blocks are indicated on the map by the following letters :

<sup>1</sup> HEIM: *Unser Wissen von der Erde*, Geogr. Anstalt. Leipsic, 1889—see map of Lake Lucerne.

<sup>2</sup> Das Keupenbecken am. 4—Waldstätter See, *Neues Jahrbuch*, etc., 1890, II. p. 99 ff.

<sup>3</sup> Beiträge z. geol. Karte der Schweiz, Vol. XXIV., pp. 282–285, 524.

<sup>4</sup> See *Berichte der Naturforsch. Geo. zur Freiburg i B.*, Vol. IX., No. 2, p. 122 ff.

<sup>5</sup> See FAVRE: *Carte geol. d. voisines du Mont Blanc*, Winterthur, 1862.

- A Easternmost group = Bolgen group—west of the Iller valley.
- B = Barlaui Alp group—northeast of Iberg.
- C = Tannstaffelalp group--in Wäggi valley east of Iberg.
- D = Steinibach group, four to six kilometers north of Iberg.
- E = Geschwend-Surbrunnen group—one to two kilometers north of Iberg.
- F = Gründelhüttli group, west of Iberg.
- G = Giswyl group, near Giswyl.
- H = Flühli group, northwest of Giswyl.
- I = Habkern group, in Habkern valley.

At the south edge of Freiburg Alps southwest of Lake Thun may be mentioned :

- J = Lenk-Lauenen group, between Bad Lenk and Lauenen.

At the west end of the Rhine-Thun cliff zone are seen the Alps of Freiburg and Chablais. It should be noted that the southern edge of these Alps are in line with the southern limit of cliff distribution; the northern border, on the other hand, is not in line with the northern border of the Swiss Alps, but extends in the form of a bow far out into the Miocene plains (Molasse land). In the upper valleys of the Saane and Simmen rivers (see map) where these valleys are cut deeply into the Freiburg strata typical Helvetian strata, Flysch and Nummulitic limestone have been found lying below Triassic and Jurassic strata in Freiburg facies,<sup>1</sup> indicating that the Freiburg Alps at this point were thrust southward two and one-half to four and one-half kilometers over the Helvetian strata. We have, therefore, drawn a dotted line across the southern portion of the Freiburg-Chablais zone to indicate the probable zone of overthrust and colored all south of this zone black. It may, however, be that this overthrust is of a more local nature. The remainder of the region is striped diagonally black and white.

To the east of the Rhine-Thun cliff zone the area of the strata in East Alpine facies is roughly indicated by alternating

<sup>1</sup> Cf. *Berichte d. Naturforschende Gesell. v. Freiburg i. B.* Vol. IX., Part 2, p. 122, 1894.



bands of black and white running horizontally. It will be seen that the East Alps do not begin at once at the Rhine, but there is a promontory-like wedge of Helvetian strata (fine black horizontal lines) projecting along in front of their north border a considerable distance. In this wedge occur the enigmatical exotic bowlders by Bolgen (A of the map).

It will be noticed that the cliffs and exotic blocks are scattered with considerable irregularity along the north border of the Alps over a belt of Helvetian strata (indicated by the light horizontal lines) from about two to nearly nine kilometers broad. The exotic masses do not extend anywhere south of this strip. In the vicinity of Iberg, which has been studied with especial thoroughness, may be seen how the whole region between the southern border of the cliff belt and the northern border of the Helvetian chains is covered with exotic material. Abundant as is this exotic material here, every trace of it disappears a short distance south of the cliffs. This most striking limitation of the distribution of the exotic strata southward all along the Thun-Rhine cliff belt is precisely what we would expect if there had been an overthrust like that hypothesized.

*Summary and conclusion.*—To recapitulate, we have found Alpine facies in the Freiburg Alps at the west end of the cliff zone, Alpine facies again at the east end in the "East Alps," Alpine facies also in the superficial cliffs and exotic blocks between these two points. In the Nagelfluh we have evidence of a former much greater extent of the cliff masses. In the cliffs themselves and in the fact that cliffs and exotic blocks lie invariably in Flysch we find evidence that they were thrust over Flysch; lastly, in the supposed Vindelicic system beneath the Miocene plains north of the cliffs we have a place—and apparently the only place—from which it seems possible that the cliffs could have been derived. These conclusions afford us the most satisfactory explanation of the cliff belt and the Freiburg-Chablais region as a whole and their relations to the East Alps, and render intelligible the presence of the Swiss plains—sunken between the "horsts" of the Alps and the Jura—and the isolated position of the Jural mountains on the far side of them.

Bearing in mind the geographic relations of Cliff-Freiburg-Chablais exotic belt we can, in accordance with the above view, reconstruct in some measure the geographic conditions of this part of the world in early and middle Mesozoic times. According to this view there extended in Jura-Trias times between the present site of the Alps and the Jural mountains opposite a Vindellic sea in which East Alpine life and conditions prevailed. A comparison of the exotic (Vindellic) series with the Helvetian and Jurassic faunas shows beyond doubt that the cliff series represent deposits in comparatively deep water.<sup>1</sup> We may, therefore, assume that the sea of this region was at that time characterized along the Vindellic area by a deeper sea. If the passage from the more shallow Helvetian to the deeper Vindellic sea was not too abrupt we might therefore expect to find indications of transition in the outermost (northernmost) chains of the Alps. Hence the fact pointed out by Stutz that along the Axenstrasse on the Lake of Lucerne the outer chains contain certain subordinate beds of more Alpine facies (Diphyra-beds, "Stramberg beds"—strata with *Terebratula janitor*) has a peculiar interest. And the fact that certain of the cliff strata have been shown to present facial similarity to others occurring on the north side of the Vindellic region would further bear out this conception by showing a relationship between the cliff series and strata to the north.

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<sup>1</sup> As evidenced, for example, by the presence of *Aptychus* limestone, *Globigerina* shales, Radiolarian chert and associated red clay in the cliffs.